

REPORT DOCUMENTATION PAGE			Form Approved OMB NO. 0704-0188		
<p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA, 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</p>					
1. REPORT DATE (DD-MM-YYYY) 05-10-2014		2. REPORT TYPE Conference Proceeding		3. DATES COVERED (From - To) -	
4. TITLE AND SUBTITLE Photonic Jets for Strained-Layer Superlattice Infrared Photodetector Enhancement			5a. CONTRACT NUMBER W911NF-09-1-0450		
			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT NUMBER 611102		
6. AUTHORS Kenneth W. Allen, Joshua M. Duran, Gamini Ariyawansa, Jarrett H. Vella, Nicholaos I. Limberopoulos, Augustine M. Urbas, Vasily N. Astratov			5d. PROJECT NUMBER		
			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAMES AND ADDRESSES University of North Carolina - Charlotte 9201 University City Boulevard Charlotte, NC 28223 -0001			8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES) U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211			10. SPONSOR/MONITOR'S ACRONYM(S) ARO		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S) 54377-MS.61		
12. DISTRIBUTION AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.					
14. ABSTRACT Photonic jets are light beams focused by dielectric microspheres down to subwavelength dimensions. In this work we show that they can be used for enhancing performance of strained-layer superlattice (SLS) infrared (IR) photodiodes in the midwave-infrared spectral band (3-5 μm). We optimized the design of these structures and experimentally demonstrated the increased sensitivity compared to conventional photodetectors.					
15. SUBJECT TERMS photonic jets, photodetectors, photodiodes, strained-layer superlattice, midwave-infrared, sensitivity of photodetectors, microspheres					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Vasily Astratov
a. REPORT UU	b. ABSTRACT UU	c. THIS PAGE UU			19b. TELEPHONE NUMBER 704-687-8131

Report Title

Photonic Jets for Strained-Layer Superlattice Infrared Photodetector Enhancement

ABSTRACT

Photonic jets are light beams focused by dielectric microspheres down to subwavelength dimensions. In this work we show that they can be used for enhancing performance of strained-layer superlattice (SLS) infrared (IR) photodiodes in the midwave-infrared spectral band (3-5 μm). We optimized the design of these structures and experimentally demonstrated the increased sensitivity compared to conventional photodetectors.

Conference Name: National Aerospace and Electronic Conference (NAECON)

Conference Date: June 25, 2014

Photonic Jets for Strained-Layer Superlattice Infrared Photodetector Enhancement

Kenneth W. Allen,^{1,2} Joshua M. Duran,² Gamini Ariyawansa,^{2,4} Jarrett H. Vella,⁵ Nicholaos I. Limberopoulos,² Augustine M. Urbas,³ and Vasily N. Astratov^{1,2*}

¹Department of Physics and Optical Science, Center for Optoelectronics and Optical Communications, University of North Carolina at Charlotte, 9201 University City Blvd., Charlotte, NC 28223-0001, USA

²Sensors Directorate, United States Air Force Research Laboratory, Wright-Patterson AFB, OH 45433, USA

³Materials and Manufacturing Directorate, United States Air Force Research Laboratory, Wright-Patterson AFB, OH 45433, USA

⁴UES, Dayton, OH 45433, USA

⁵Wyle, Dayton, OH 45433, USA

*Tel: (704) 687 8131, Fax: 1 (704) 687 8197, Email: {kallen62, astratov}@unc.edu

Abstract— Photonic jets are light beams focused by dielectric microspheres down to subwavelength dimensions. In this work we show that they can be used for enhancing performance of strained-layer superlattice (SLS) infrared (IR) photodiodes in the midwave-infrared spectral band (3–5 μm). We optimized the design of these structures and experimentally demonstrated the increased sensitivity compared to conventional photodetectors.

Keywords— photonic jets; photodetectors; photodiodes; strained-layer superlattice; midwave-infrared; sensitivity of photodetectors; microspheres

I. INTRODUCTION

Over the course of the past decade there has been significant development in regards to the fundamental properties and potential applications of photonic nanojets (PNJs) [1–3] and nanojet-induced modes (NIMs) [4–10], spanning the areas from biomedical optics to super-resolution imaging [11,12]. Dielectric microspheres provide strong concentration of electromagnetic power which can be used for ultraprecise surgery and for increasing the sensitivity of the photodetector devices [13].

In this work, we used InAs/GaSb strained-layer superlattice IR photodiodes integrated with microspheres for focusing light in the near-surface active region of the detectors. Our numerical modeling results indicate that the optimal index of refraction of the microspheres for these detectors is $n=1.8$. Experimentally, we used soda-lime glass microspheres with sub-optimal index ($n=1.44$ in midwave-infrared) and demonstrated an order of magnitude increase of the sensitivity of the strained-layer superlattice (SLS) infrared photodiodes.

II. NUMERICAL DESIGN

Modern IR photodetector devices often have active regions with the lateral dimensions below 30 μm and a thickness of a few microns located close to the surface of the structure. Our design goals were to: i) optimize the depth of focusing at a micron-scale depth below the surface of a high-index slab and ii) minimize the lateral dimensions of the PNJ.

Two-dimensional simulations were performed by finite element modeling using COMSOL Multiphysics for the wavelength of light $\lambda = 4 \mu\text{m}$. As shown in Fig. 1 (a), a dielectric cylinder was placed at the top of a dielectric slab with $n = 3.3$. We demonstrated that the optimal sphere index for focusing light in near-surface region of the slab is $n=1.8$, as illustrated in Fig. 1 (b). We also showed that the transverse width of the beam at its waist is about $\lambda/3$, as illustrated in Fig. 1 (c).

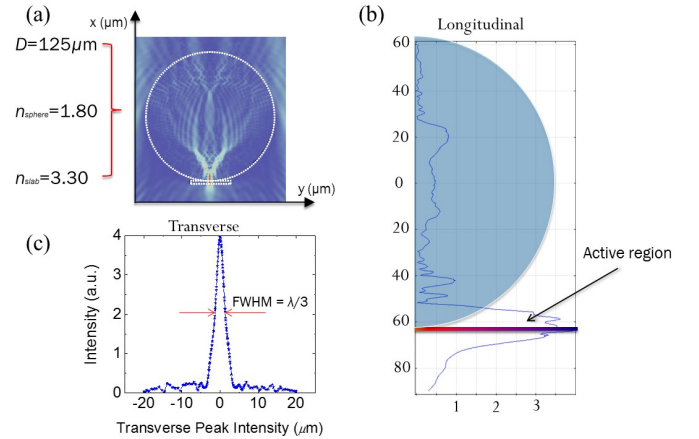


Fig. 1: (a) Electric field map calculated for a plane wave illumination of a 125 μm diameter cylinder with $n=1.80$. (b) Longitudinal line profile of the irradiance, showing the beam waist in the near-surface region of the slab. (c) Transverse line profile through the peak of the longitudinal line profile.

III. EXPERIMENTAL

A soda-lime sphere with diameter $D = 212 \mu\text{m}$ and $n \sim 1.47$ was integrated on to the top of a 40 μm photodetector fixed into position using a silicone rubber. As illustrated in Fig. 2, the spectral response was characterized before and after positioning the microsphere. The results illustrate an order of magnitude enhancement of the sensitivity of the detector equipped with the focusing microsphere. The dip around 3.3 μm is likely due to absorption in soda-lime glass.

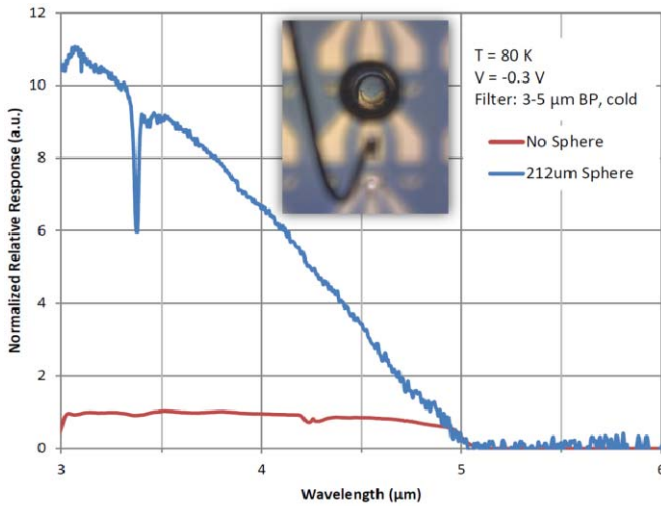


Fig. 2: Direct comparison of the photocurrent, with and without the soda-lime ($D = 212 \mu\text{m}$, $n \sim 1.47$).

The decreasing response from 3 to 5 μm is possibly a result of poor IR transmission of the glass but requires further studies which will be performed in the future.

IV. SUMMARY

In this work, we demonstrated that the focusing effects produced by dielectric microspheres allow significant enhancement of the sensitivity of midwave-IR photodetectors.

ACKNOWLEDGMENT

The authors thank I. Vitebskiy, J. Derov, R. Ewing and M. Schmitt for stimulating discussions. This work was supported by the U.S. Army Research Office (ARO) through Dr. J. T. Prater under Contract No. W911NF-09-1-0450 and by Center for Metamaterials, an NSF I/U CRC, award number 1068050. This work was sponsored by the Air Force Research

Laboratory (AFRL/RYP) through the AMMTIAC contract with Alion Science and Technology.

REFERENCES

- [1] V. N. Astratov, *Photonic Microresonator Research and Applications*, Springer Series in Optical Sciences vol. 156, edited by I. Chremmos, O. Schwelb, and N. Uzunoglu (Springer, New York, 2010), Ch. 17, pp. 423-457.
- [2] Z. Chen, A. Taflove, and V. Backman: Photonic nanojet enhancement of backscattering of light by nanoparticles: a potential novel visible-light ultramicroscopy technique," *Opt. Express*, vol. 12, pp. 1214-1220, April 2004.
- [3] K.W. Allen, *et al.*: Photonic Jets Produced by Microspheres Integrated with Hollow-Core Fibers for Ultraprecise Laser Surgery, *Proc. ICTON 2013*, paper Tu.P.39, 2013.
- [4] V.N. Astratov, *et al.*: Photonic nanojets for laser surgery, *SPIE Newsroom*, 12 March 2010.
- [5] K.W. Allen, A. Darafsheh, and V.N. Astratov: Photonic nanojet-induced modes: from physics to applications, in *Proc. ICTON 2011*, Stockholm, Sweden, July 2011, paper Tu.C4.2.
- [6] A. Darafsheh, *et al.*: Focusing capability of integrated chains of microspheres in the limit of geometrical optics, *Proc. of SPIE, Laser Resonator and Beam Control XIII*, 79131A, 2011.
- [7] V.N. Astratov, *et al.*: Focusing Microprobes Based on Integrated Chains of Microspheres, *PIERS*, vol. 6: 8, 793-797, 2010.
- [8] K.W. Allen, A. Darafsheh, and V.N. Astratov: Beam tapering effect in microsphere chains: from geometrical to physical optics, *Proc. of SPIE, Laser Resonators, Microresonators, and Beam Control XIV*, 823622, 2012.
- [9] A. Darafsheh, *et al.*: Formation of polarized beams in chains of dielectric spheres and cylinders, *Opt. Lett.*, vol. 38, pp. 4208-4211, Oct. 2013.
- [10] K.W. Allen, *et al.*: Microsphere-chain waveguides: Focusing and transport properties, *Appl. Phys. Lett.*, vol. 105, 021112, July 2014.
- [11] A. Darafsheh, *et al.*: Optical super-resolution by high-index liquid-immersed microspheres, *Appl. Phys. Lett.* vol. 101, 141128, Oct. 2012.
- [12] A. Darafsheh, *et al.*: Advantages of microsphere-assisted super-resolution imaging technique over solid immersion lens and confocal microscopies, *Appl. Phys. Lett.* vol. 104, 061117, Feb. 2014.
- [13] M. Hasan and J.J. Simpson: Photonic nanojet-enhanced nanometer-scale germanium photodiode, *Appl. Optics*, vol. 52, pp. 5420-5425, Aug. 2013.